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REMOTE SENSING STUDY OF MAUMEE RIVER EFFECTS ON LAKE ERIE

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16. Abstract

A preliminary report of a pilot study of the effects of river inputs on boundary waters is presented. The study was done in support of Task D of the Pollution from Land Use Activities Reference Group of the International Joint Commission. Task D has the responsibility to assess the significance of river inputs into receiving waters, dispersion of pollutants, and the effects on water quality. The objective of this effort was to assess the effects of the spring runoff of the Maumee River on Lake Erie by a combination of ship survey (Ohio State University Center for Lake Erie Area Research) and remote sensing techniques (NASA Lewis Research Center). Imagery obtained from a multispectral scanner of the west basin of Lake Erie is presented and discussed. The imagery clearly showed the distribution of particulate throughout the covered area. This synoptic view, in addition to its qualitative value, can be very useful in selecting sampling stations for shipboard in situ measurements, and for extrapolating these quantitative results throughout the area of interest.

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SUMMARY

A preliminary report of a pilot study of the effects of river inputs on boundary waters is presented. The study was done in support of Task D of the Pollution from Land Use Activities Reference Group of the International Joint Commission. Task D has the responsibility to assess the significance of river inputs into receiving waters, dispersion of pollutants, and the effects on water quality. The objective of this effort was to assess the effects of the spring runoff of the Maumee River on Lake Erie, by a combination of ship survey (Ohio State University Center for Lake Erie Area Research) and remote sensing techniques (NASA Lewis Research Center). It was not possible to do the study during a peak runoff period because of unfavorable weather conditions.

The shipboard measurements were made from two vessels, the 65-foot Hydra and a 22-foot Boston Whaler over a 1-week period beginning March 18. A report of the shipboard data is being prepared by OSU.

Remote sensing data were obtained using an 11-channel multispectral scanner with bands in the visible, near infrared, and thermal infrared. The scanner data were obtained concurrent with the boat cruises during overflights by NASA Lewis in a C-47 research aircraft. Images were made from the scanner data and delivered to OSU personnel for planning the following day's cruise. A facsimile recorder was installed on the Hydra to receive images directly. However, transmission difficulties minimized the usefulness of this approach.

Imagery obtained from the scanner of the west basin of Lake Erie is presented and discussed. The imagery clearly showed the distribution of particulate throughout the covered area. This synoptic view, in addition to its qualitative value, can be very useful in selecting sampling stations for shipboard in situ measurements, and for extrapolating these quantitative results throughout the area of interest.

INTRODUCTION

One of the objectives of the Pollution from Land Use Activities Reference Group (PLUARG) of the International Joint Commission, Great Lakes Water Quality Board is to assess the effects of river inputs on receiving waters. Specifically, the stated objectives of Activity 3 of Task D of PLUARG are (ref. 1):

1. "To assess the significance of specific contaminants gaining access to boundary waters as a result of land use activities.

2. To establish areas which may be adversely affected as a result of such inputs including a determination of the extent of dispersion of sediments offshore and the extent of impairment of water quality in boundary waters.

3. To determine degree of contamination of fish and other aquatic resources in areas exposed to higher-than-average loadings of specific contaminants."

The Task D program includes monitoring of the Genesee, Maumee, Grand (Michigan), and Menomonee Rivers, and their respective receiving lakes to determine effects during peak runoff conditions. As a first step in this program the Task D Technical Advisory Committee decided to support a pilot study focusing on the Maumee River basin in order to determine the necessary resources and procedures required for study of all four rivers.

The two objectives for the pilot study are:

(1) To identify and determine the dispersion and fate of the Maumee River pollutants in Lake Erie during the spring runoff maximum by a combination of shipboard and remote sensing surveys.

(2) To determine how "near real time" transmission of remotely sensed data to surface vessels can supplement and increase the effectiveness of shipboard data acquisition. It is intended that the results of this study be used to formulate plans for the remainder of the Task D event monitoring.

The field operations of the pilot study consisted of both shipboard direct water quality measurements and aircraft remote sensing surveys. The shipboard measurements were made by Ohio State University Center for Lake Erie Area Research (CLEAR) personnel using two vessels, the 65-foot R/V Hydra and a 22-foot Boston Whaler. In addition water samples were collected by NASA personnel on the OSU boats and taken to Cleveland for analyses. The remote sensing data consisted of multispectral scanner data (11-channel) recorded by NASA personnel on the Lewis Research Center C-47 aircraft.

The following sections of this preliminary data report will discuss the schedule of events, the multispectral scanner imagery, conclusions, and future plans.

SUMMARY OF EVENTS

The following is a summary and brief description of NASA's activities in this joint pilot study. An overview of NASA's remote sensing

flights and their coincidence with OSU's in situ sampling is presented in table 1. A detailed chronological account including aircraft and boat operations, communications, and wind conditions are found in appendix A. A copy of the western basin of Lake Erie from Chart Number 3 (fig. 1) will aid in identifying land sites on the following figures.

The OSU shipboard operations were scheduled to begin in March, after the Western Basin was generally clear of ice which might hamper ship operations. To allow OSU personnel to monitor ice conditions in the Western Basin, a facsimile recorder was installed at the OSU laboratory on South Bass Island to receive NASA side-looking airborne radar (SLAR) imagery of ice coverage in Lake Erie. This imagery was obtained as part of the Great Lakes Winter Navigation Program. As OSU prepared to begin sampling in mid-March, NASA conducted preliminary C-47 flights over the Western Basin on February 22, March 2, and March 5 (fig. 2). The intensive flight schedule began on March 15 to provide imagery for the two OSU vessels which were to begin sampling. The imagery of March 15 and 17 (figs. 3 and 4) was delivered to OSU and was available for the March 18 (fig. 5) survey conducted by OSU's Boston Whaler. On March 20 a facsimile recorder was installed on board the R/V Hydra to receive imagery while underway and while moored at Toledo, Ohio. A power supply failure in the multispectral scanner prevented any remote data collection on March 20. Flights were continued throughout the week and imagery was transmitted to the Hydra. The images received were not of good quality because of the long distance from the transmitting station, possible atmospheric interference, and poor line of sight when the Hydra was moored at Toledo. On March 23 the Hydra and the NASA C-47 aircraft were in voice communication via VHF marine band radiotelephone enabling the NASA personnel to describe the areas of high suspended particulate loading. OSU personnel aboard the Hydra received this information while sampling at station 57, and based upon this information altered the cruise plan to include station 127 (see fig. 6).

A total of nine flights were completed in the thirty-day period, five previous to in situ sampling activities and four concurrent with it. Weather conditions precluded the coincidence of aircraft and vessel activities on March 19 and 22. On March 22 the boats could not sample due to high seas (see appendix A). Lewis personnel conducted all flights and completed the imagery and mosaics following them. Computer classification of the scanner data is presently underway at Lewis (see Conclusions and Recommendations). Lewis personnel were aboard the Hydra on March 20 and 21 to observe operations and receive imagery transmissions. Suspended solids analyses (appendix B) were completed by a commercial laboratory. Maumee River water levels (appendix C) were collected by OSU at Waterville, Ohio, and Lake Erie levels at Toledo (appendix D) by the NOAA Lake Survey Center. Wind conditions (appendix A) were recorded at the Toledo Coast Guard Station and made available by the National Weather Service.

MULTISPECTRAL SCANNER IMAGERY

Scanner imagery are presented in figures 2 to 8. The imagery of fig-

ure 7 shows channels 2, 4, 6, 8, and 10 and the thermal channel of the March 17 multispectral scanner data. These channels correspond to wavelengths centered at 465 (50), 560 (40), 640 (40), 720 (40), and 1015 (90) nanometers, respectively, with the corresponding band width shown in parentheses. The images were obtained by recording the scanner data on high density digital tape during flight and then later playing it back, converting it to analog and recording it on a fiber optics recorder. The gray scale levels for each channel were adjusted individually so as to give the highest return (white) where the particulate load was known to be heaviest, and the lowest return (black) where the particulate load was known to be lowest. This would provide the greatest possible number of gray scales for areas of intermediate particulate load. (One should be cautioned not to compare the relative brightness of two channels.)

Each image shows the western end of Lake Erie from Toledo to the Detroit River on March 17 and was made in two flight lines at 10 000 feet. Land features such as Interstate 75 are very prominent in the lower wavelength channels. However, channel 10 and the thermal channel show very few land features because it was necessary to adjust the gray scale to bring out features in the water.

At the time of this flight ice was nearly absent from the Western Basin except for areas near the Bass Islands and Kelleys. Some ice still did remain in the Detroit River, near the Canadian shore, and east of Stony Point. The ice can be seen in all channels except the thermal. (The ice was at the same temperature as the water, within the resolution of the scanner data.) Ice can also be seen on March 15 and 18 in figures 3 and 5. By March 23 (fig. 6) ice was no longer apparent.

From a study of ERTS-1 imagery and previous machine processing of the data it was expected that channels 4 to 8 would be the most useful for detecting areas of suspended particulate. This is confirmed in figure 7. Channels 2 and 10 do not appear to show any particulate information, while channels 4, 6, and 8 all show suspended particulate patterns in the water. For example, channels 6 and 8 show a very noticeable effect along the shipping channel in Maumee Bay, especially channel 8. The channel and the Maumee River are darker than the adjacent water, expecially the water to the east of the channel. This indicates that the high particulate concentrations east of the channel are due to resuspended sediments, and that due to the Maumee River inflow are of secondary importance. Particulate resuspension was probably due to wind. Wind would have a greater effect on the shallow water adjacent to the relatively deep channel.

The thermal channel of figure 7 also provides some useful information. A thermal plume can be seen in the shipping channel which has the same shape as in channel 8, except that the areas of high return in channel 8 are areas of low return in the thermal channel. The lighter areas are areas of relatively warmer water. In this case water adjacent

to the channel is shallow and subject to wind mixing. In the shallow water the temperature is probably the same at all depths and mixing would not change the surface temperature. Because of its greater depth though, the channel probably has a temperature gradient, with the surface water at 0° C and the bottom water at 4° C. Wind mixing could cause relatively warmer water from below the surface to be brought to the surface to form the observed thermal plume.

It is apparent that a synoptic view of the area is very useful in making these deductions. The main conclusion is that the high suspended particulate load appears to be caused by resuspension rather than Maumee River outflow.

Thermal plumes from powerplants are also visible. Thermal plumes located at the Consumers Power Plant and Detroit Edison Monroe Power Plant in Michigan, and Toledo Edison's Bay Shore Power Plant can be seen emanating from their respective sources. (These are indicated by arrows in fig. 7.) Winds from the north kept the plumes from the Michigan power plants from extending into the lake. The plumes are seen hugging the shoreline southward from their sources. The plume from the Bay Shore Power Plant appears just east of the L-shaped dredging disposal area in the lake on the east side of the Maumee River. This can be compared to figure 8 of the thermal channel for March 23. On this day the same plumes may be seen as on March 17 (fig. 7). Notice that the plume along the shipping channel on March 17 is no longer present on March 23. A more extensive study of thermal plumes has been reported by the Environmental Protection Agency (ref. 2).

To present the imagery for each flight it was decided to select one channel which gave the best overall display of suspended particulate distribution. This was channel 6. The images are shown in figures 2 to 6 for flights of March 5, 15, 17, 18, and 23. The original images were made to the same scale as Lake Erie Chart No. 39 in order to facilitate the translation of locations of land and water sites from the chart to the images. (White lines on the images were caused by intermittent data system malfunctions.) A complete table of the suspended particulate data is shown in appendix B.

Coinciding flight imagery and in situ data were obtained only on March 18, 21, and 23. On March 18 scattered clouds covered some of the Western Basin and there is uncertainty as to whether some areas on the imagery are showing suspended particulate or cloud cover. This ambiguity can possibly be removed by computer processing. On March 21 there were very rough seas and little in situ data were obtained. On March 23 the skies were clear and in situ data were obtained for suspended solids at locations shown in figure 6. There appears to be qualitative agreement between aircraft imagery and the shipboard data in appendix B. Quantitative comparison of the ground truth data with the scanner data will be done by computer.

As mentioned earlier, the Hydra and the NASA C-47 had radiotelephone communication on March 23 while the C-47 was overflying the Western Basin

and the Hydra was at station 57. As a result of the communication the Hydra included station 127 (see fig. 6) in its survey. However, if suspended particulate information could have been transmitted to the Hydra earlier, the cruise plan could have been altered to include other stations where the suspended particulate load was heavy. For instance, station 61 was in a band of low suspended particulate, whereas heavier suspended particulate was located to the east and northwest. This illustrates the importance of getting timely aircraft imagery to the vessels to aid in selecting point monitoring sites. The imagery yields immediate qualitative information of the distribution of suspended solids throughout the covered area. Furthermore, computer analysis of the multispectral scanner imagery may permit quantitative extrapolation of the in situ data at selected sites to give a more complete description of the distribution through the imaged area.

Suspended particulate patterns appear in all of the images in Maumee Bay and along the Ohio shore line, though ground fog covered the southeast portion of the image of March 17 and scattered clouds are visible on the March 18 image. Water levels in the Maumee River were never sufficient during this time period to provide a significant discharge into Lake Erie (see appendix C). Considering the high winds during some of the days a considerable amount of resuspended sediment could be present. Computer analysis of the data may determine which particulate is from resuspension and which originates from the Maumee River inflow.

IN SITU DATA

Water samples were obtained from the cruises of March 18, 20, 21, 23, and 24 and analyzed for suspended solids under contract. The results are summarized in appendix B. Samples were filtered and dried at 90° C for 24 hours and then ashed at 500° C for 12 hours. The ratio ash-free dry weight to total dry weight gives an approximate fraction of organic material in the total suspended particulate.

Duplicate analyses were run from each sample taken. Some differences between duplicates were unexpectedly high, though in most cases the differences were within the expected accuracy.

Four samples also were collected for a determination of particle size at stations 59, 70, and 105 from March 20 and station 141 on March 21. These samples were run on a Coulter Counter using a 100μ aperture and the results are shown in figure 9.

CONCLUSIONS AND RECOMMENDATIONS

The primary conclusion that can be drawn from the preliminary data is that the synoptic view provided by even a single channel of scanner data provides significant information concerning the overall location of suspended particulate in the Western Basin. Even without the quantitative

correlation of image gray scale to water parameters, the distribution of suspended particulate and details of plumes are usually apparent.

This ability to map particulate patterns is of value in three areas of application: (1) Imagery showing the particulate patterns can be used to complement ship survey point measurements. Information obtained at various discrete sampling sites can be extrapolated to similar areas at which ship data were not recorded. In this way more accurate estimates of quantities such as total suspended particulate load are obtained than could be produced by point measurements alone. (2) Particulate maps of large area can be of use in efficiently planning ship surveys if the data is transmitted to the boats in a timely manner. Although near real time transmission of remotely sensed data to the survey ship was not achieved in this pilot study, it is apparent that the sampling ship could have selected its sites more effectively had the imagery been transmitted to it in time. (3) The synoptic nature of the remote sensing imagery permits the delineation of features on a large scale which may not be apparent to shipboard observers. Such imagery can provide information concerning the interaction of plumes from different rivers or point sources, resuspension of sediment, as well as the development of plumes across international boundaries.

Another result of the preliminary analysis concerns the multispectral characteristics of the scanner data. As discussed earlier, figure 7 indicates in a visual way the fact that different scanner data channels contain different kinds of information. It is also recognized that computer processing of the multispectral data using well established techniques can yield information not obtainable from single channel images taken single or collectively. For example, computer classification of multispectral data might provide a basis for distinguishing between resuspended and runoff related sediment. One concludes that the potential of using multispectral data analysis techniques to provide information of pertinence to PLUARG Task D goals could be significant.

The weather this year was unusual. A peak runoff which usually occurs in the Maumee River after the spring thaw in March did not occur. One peak river discharge did occur near the end of February (appendix C) when ice was present in the West Basin and ships would have been unable to acquire data. It is believed that a peak land runoff also occurred at this time, but inasmuch as no flights were made during this time period it was not confirmed. Aircraft or satellite imagery seems to be the only way to determine river outflow extent when ice prevents ship surveys.

Also because of the limited number of survey ships available and because of the high operating costs, it is not practical to keep a vessel idly waiting for an event to occur. One approach may be to use smaller vessels which could be dedicated for the event monitoring in combination with satellite or aircraft over flight.

REFERENCES

1. Plan of Study for U.S. Task D Study on Great Lakes Pollution from Land Use Activities. Great Lakes Basin Commission, 1975.

2. Remote Sensing Study of Stream-Electric Power Plant Thermal Discharges to Lake Erie, Detroit, and St. Clair Rivers in Ohio and Michigan. Natl. Field Investigations Center - Denver, 1974.

APPENDIX A

CHRONOLOGICAL TABLE OF EVENTS

DATE	REMOTE SENSING	IN SITU SAMPLING	COMMUNICATIONS	WIND CONDITIONS TIME (EDT)	DIRECTION (DEGREES)	MAGNITUDE (KNOTS)
22 FEB	(AM) Preliminary flight-3 flight lines					
25 FEB			Facsimile receiver installed at OSU Lab on South Bass Island to receive SLAR ice imagery			
1 MAR				0200	270	08
				0800	290	10
				1400	290	15
				2000	290	05
2 MAR	(AM) Preliminary flight-3 flight lines			0200	290	15
				0800	290	08
				1400	310	20
				2000	360	16
3 MAR				0200	310	15
				0800	290	10
				1400	340	12
				2000	240	10
4 MAR				0200	290	11
				0800	290	08
				1400	220	12
				2000	200	04

DATE	REMOTE SENSING	IN SITU SAMPLING	COMMUNICATIONS	WIND CONDITIONS TIME (EDT)	DIRECTION (DEGREES)	MAGNITUDE (KNOTS)
5 MAR	(AM) Preliminary flight-12 flight lines (Figure 2 shows 4 flight lines)			0200	180	05
				0800	200	04
				1400	250	15
				2000	200	08
*13 MAR				0200	270	10
				0800	340	12
				1400	360	10
				2000	060	10
14 MAR				0200	040	26
				0800	060	10
				1400	020	10
				2000	360	18
15 MAR	(AM) Flight-10 flight lines (Figure 3)			0200	240	04
				0800	200	05
				1400	200	04
				2000	220	12
16 MAR				0200	200	01
				0800	110	03
				1400	090	05
				2000	090	03
17 MAR	(PM) Flight-9 flight lines (Figure 4)	Boat operations delayed as equipment is installed	Mosaic of MAR 15 delivered to OSU personnel	0200	040	05
				0800	020	10
				1400	---	--
				2000	060	08

*No operations between March 5 and March 15. R/V Hydra was being outfitted.

DATE	REMOTE SENSING	IN SITU SAMPLING	COMMUNICATIONS	WIND CONDITIONS TIME (EDT)	DIRECTION (DEGREES)	MAGNITUDE (KNOTS)
18 MAR	(AM) Flight 12 Flight lines (fig. 5)	Whaler went from S. Bass Island to Toledo (8 stations)	Imagery of MAR 17 delivered to OSU personnel	0200 0800 1400 2000	090 130 160 110	10 07 12 04
19 MAR	No Flights (overcast, rain)	Hydra went from South Bass Island to Toledo. (1 station). Whaler operated out of Toledo (16 stations)		0200 0800 1400 2000	160 360 040 310	12 04 04 09
20 MAR	(AM) Flight No imagery due to scanner power failure (PM) Flight to Ann Arbor, MI, to repair scanner.	Hydra (13 stations) and Whaler (18 stations) operate in West Basin NASA personnel on Hydra	Facsimile receiver installed on Hydra Imagery received on Hydra while in West Basin.	0200 0800 1400 2000	310 290 360 060	07 03 05 09
21 MAR	(AM) Flight 15 Flight Lines	Very limited sampling by Hydra (3 stations) and Whaler (4 stations). Due to rough seas NASA personnel on Hydra.		0200 0800 1400 2000	060 110 060 090	10 10 15 12
22 MAR	No Flight (overcast, low ceilings, high winds)	No boat activity (rough seas)		0200 0800 1400 2000	090 160 290 290	07 10 25 15

DATE	REMOTE SENSING	IN SITU SAMPLING	COMMUNICATIONS	WIND CONDITIONS TIME (EDT)	DIRECTION (DEGREES)	MAGNITUDE (KNOTS)
23 MAR	(AM) Flight 10 Flight Lines (figs. 6, 8)	Hydra operating out of Toledo (9 stations)	Communication between C-47 and Hydra via marine band radio	0200 0800 1400 2000	270 360 060 090	06 03 10 15
24 MAR	No Flight	Hydra (4 stations) on return to South Bass Island		0200 0800 1400 2000	060 090 180 270	25 09 18 20

Wind conditions recorded at U.S. Coast Guard Station, Toledo, Ohio

APPENDIX B

SUSPENDED SOLIDS

STATION	DRY WEIGHT (mg/1)		ASH-FREE DRY WEIGHT (mg/1)	
	RUN 1	RUN 2	RUN 1	RUN 2
		MARCH 18, 1975		
070	56.0	54.0	14.0	8.3
113	22.0	23.0	12.0	10.1
120	53.0	53.0	10.0	11.0
132	87.0	31.0	11.0	9.0
135	49.0	52.0	6.0	7.0
139	23.0	16.5	2.0	2.2
140	21.0	19.0	5.0	3.6
141	36.0	35.0	11.0	9.2
		MARCH 20, 1975		
058-1 meter	18.3	21.0	4.0	5.0
058-5 meter	21.0	22.6	7.0	5.3
059	16.1	16.1	3.2	3.2
070	36.0	31.0	6.0	5.0
101	40.2	43.0	5.6	6.0
105	4.0	3.2	1.0	1.0
113	6.0	10.3	5.0	6.2
120	12.0	15.3	1.0	2.0
123	19.4	18.6	6.9	6.3
124	47.3	56.8	7.3	8.4
127	20.7	24.6	5.1	6.2
128	35.0	34.0	12.0	12.3
132	16.0	17.5	6.0	9.0
135	17.3	28.7	8.2	8.6
139	22.7	31.2	7.3	5.0

SUSPENDED SOLIDS (CONTINUED)

STATION	DRY WEIGHT (mg/l) RUN 1	DRY WEIGHT (mg/l) RUN 2	ASH-FREE DRY WEIGHT (mg/l) RUN 1	ASH-FREE DRY WEIGHT (mg/l) RUN 2
		MARCH 21, 1975		
139	21.3	17.5	6.7	5.8
*140A	9.0	10.1	4.0	3.6
*140B	30.0	32.5	6.0	7.1
141	32.0	37.2	5.0	6.0
150	74.0	86.0	10.0	10.2
151	21.0	15.0	4.0	3.0
152	26.0	25.0	8.0	8.0
153	29.6	33.2	9.6	10.1
		MARCH 23, 1975		
57	11.6	12.5	1.4	2.3
60	6.8	12.7	1.2	2.5
61	9.2	9.0	2.0	1.0
70	29.2	37.0	6.0	8.0
120	10.4	9.0	2.8	3.0
127	67.3	69.0	23.3	23.0
132	46.0	51.1	8.0	9.7
135	57.3	57.6	8.4	8.8
139	55.5	55.0	9.1	9.0
		MARCH 24, 1975		
70	68.0	71.0	10.0	12.0
75	15.6	13.4	7.8	5.8
76	41.3	44.2	4.7	5.1
139	55.3	60.0	6.7	8.0

*The discrepancy between these duplicate samples is unresolved. Duplicate samples taken during other research cruises have shown a much smaller difference in general.

APPENDIX C

MAUMEE RIVER WATER LEVELS AT WATERVILLE, OHIO

DATE (1975)	TIME (EST)	LEVEL (ft.)
2/24	1615	10.77
2/25	0745	11.17
2/26	1630	11.09
2/27	1800	9.87
2/28	1640	8.35
3/1	1210	7.28
3/2	1650	6.26
3/3	1625	5.42
3/4	1730	4.59
3/6	0645	3.80
3/7	1645	3.77
3/8	1100	4.80
3/9	1140	5.18
3/10	1620	4.86
3/11	1625	4.36
3/12	1645	4.27
3/13	1700	4.24
3/14	1650	4.53
3/15	1600	4.15
3/16	1500	3.91
3/17	1730	3.94
3/18	1610	4.42
3/19	1605	4.89
3/20	2020	5.17
3/21	1630	5.00
3/22	1122	5.02
3/23	1653	4.24
3/24	1728	4.25
3/25	1610	4.04

APPENDIX D

LAKE ERIE WATER LEVELS AT TOLEDO, OHIO

DATE (1975)	TIME OF MAXIMUM (EST)	LEVEL (ft)* MAXIMUM	MINIMUM
2/24	0100	5.18	2.95
2/25	0700	3.71	-0.04
2/26	2300	3.45	-0.38
2/27	2400	4.06	1.75
2/28	0400	4.15	2.33
3/1	0400	3.93	3.00
3/2	2200	4.07	3.15
3/3	1400	3.92	2.65
3/4	0500	4.07	3.25
3/5	2300	4.19	3.49
3/6	1800	4.23	3.30
3/7	0600	5.03	3.08
3/8	1300	4.80	3.07
3/9	0500	4.70	3.14
3/10	1000	4.65	3.56
3/11	2200	4.54	3.83
3/12	0100	4.36	3.42
3/13	2000	4.76	3.58
3/14	0900	7.92	4.25
3/15	1100	4.33	2.96
3/16	1300	4.34	3.74
3/17	2400	4.56	3.88
3/18	0100	4.47	3.93
3/19	0100	4.28	3.59
3/20	2400	4.31	3.77
3/21	1300	5.45	4.25
3/22	0100	4.97	2.49
3/23	0100	5.59	3.17
3/24	0500	5.93	2.53
3/25	2400	3.88	2.40
3/26	1800	4.72	3.71
3/27	2200	5.90	4.18
3/28	0800	5.63	4.58
3/29	0100	4.76	3.07
3/30	0800	3.42	0.87
3/31	2200	4.69	2.47

*Level = level above low water datum (568.6 ft)

TABLE 1. - SUMMARY OF EVENTS[a]

Date	Flight	Mosaic	Figure	Ship operations	Number of stations
Feb. 22	x				
Mar. 2	x				
Mar. 5	x	x	2		
Mar. 15	x	x	3		
Mar. 16					
Mar. 17	x	x	4,7		
Mar. 18	x	x	5	Boston Whaler	8
[b]Mar. 19				Hydra Boston Whaler	17
[c]Mar. 20	x			Hydra Boston Whaler	31
[d]Mar. 21	x				7
[e]Mar. 22					0
Mar. 23	x	x	6,8		9
Mar. 24				Hydra Boston Whaler	4

[a]For a more detailed account see appendix A.

[b]Low clouds, rain; no flights.

[c]Scanner power failure; no data.

[d]Clouds, high winds; limited aircraft imagery and limited ship operations.

[e]Clouds, rain, high winds; no flights or ship operations.

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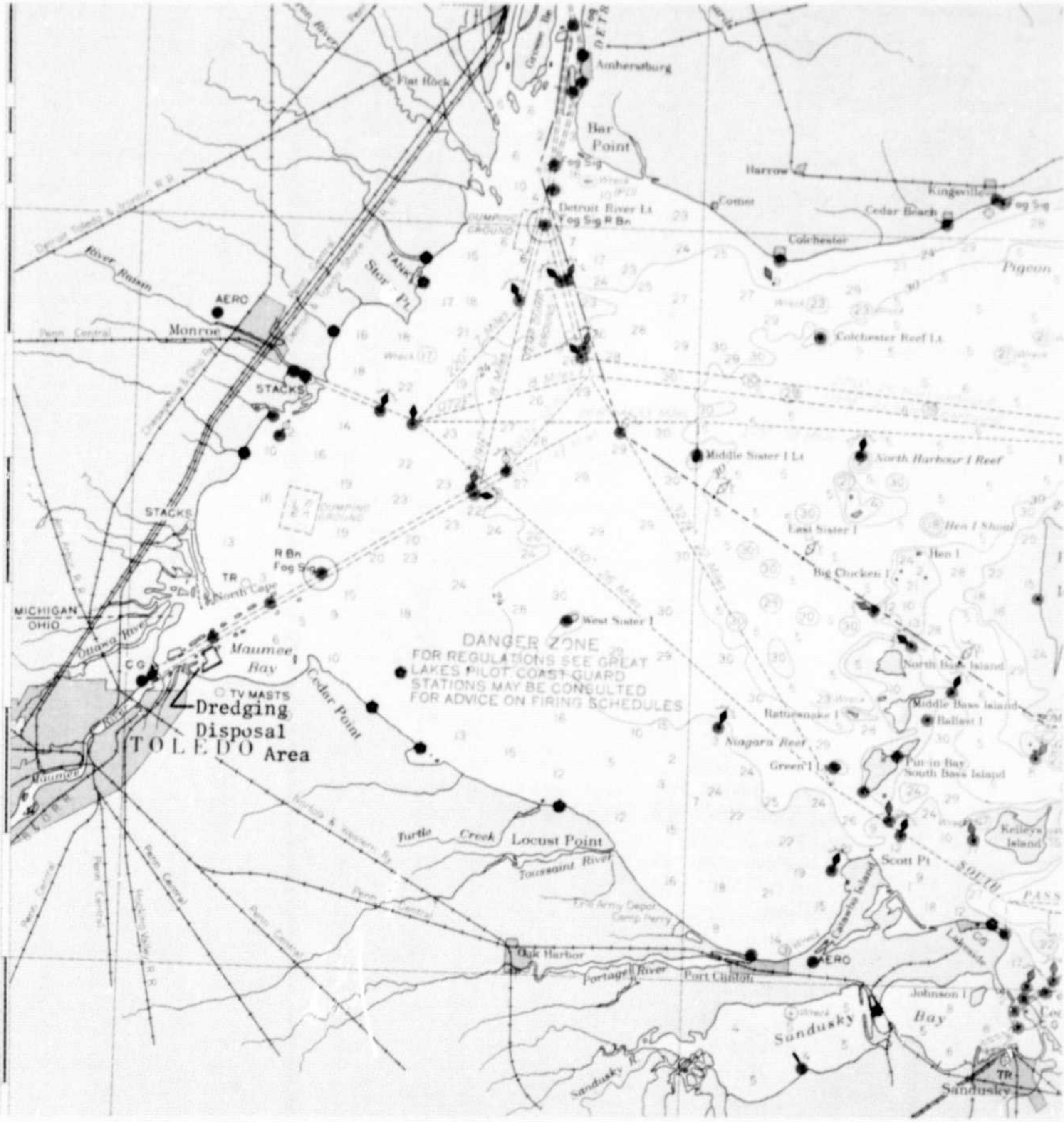

FIGURE 1

WESTERN LAKE ERIE

Taken from the National Oceanic and Atmospheric Administration Lake Survey Chart No. 3, December 1971, corrected to January 26, 1973

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MARCH 5, 1975

CHANNEL 6 (640 nm) ALTITUDE - 10,000 FT.

FIGURE 2

MULTISPECTRAL SCANNER IMAGERY OF WESTERN LAKE ERIE

MARCH 15, 1975

CHANNEL 6 (640 nm) ALTITUDE - 10,000 FT.

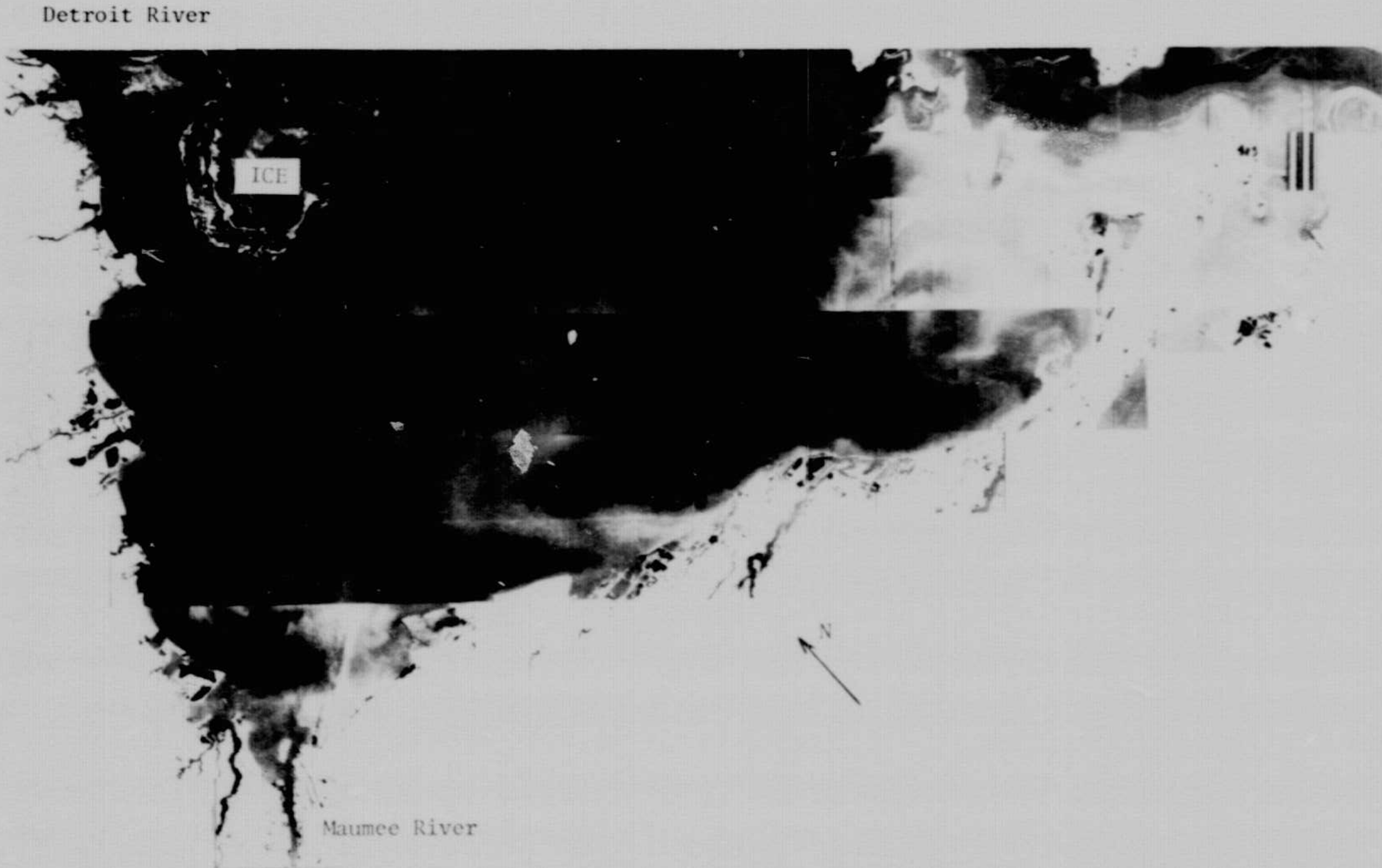

FIGURE 3

MULTISPECTRAL SCANNER IMAGERY OF WESTERN LAKE ERIE

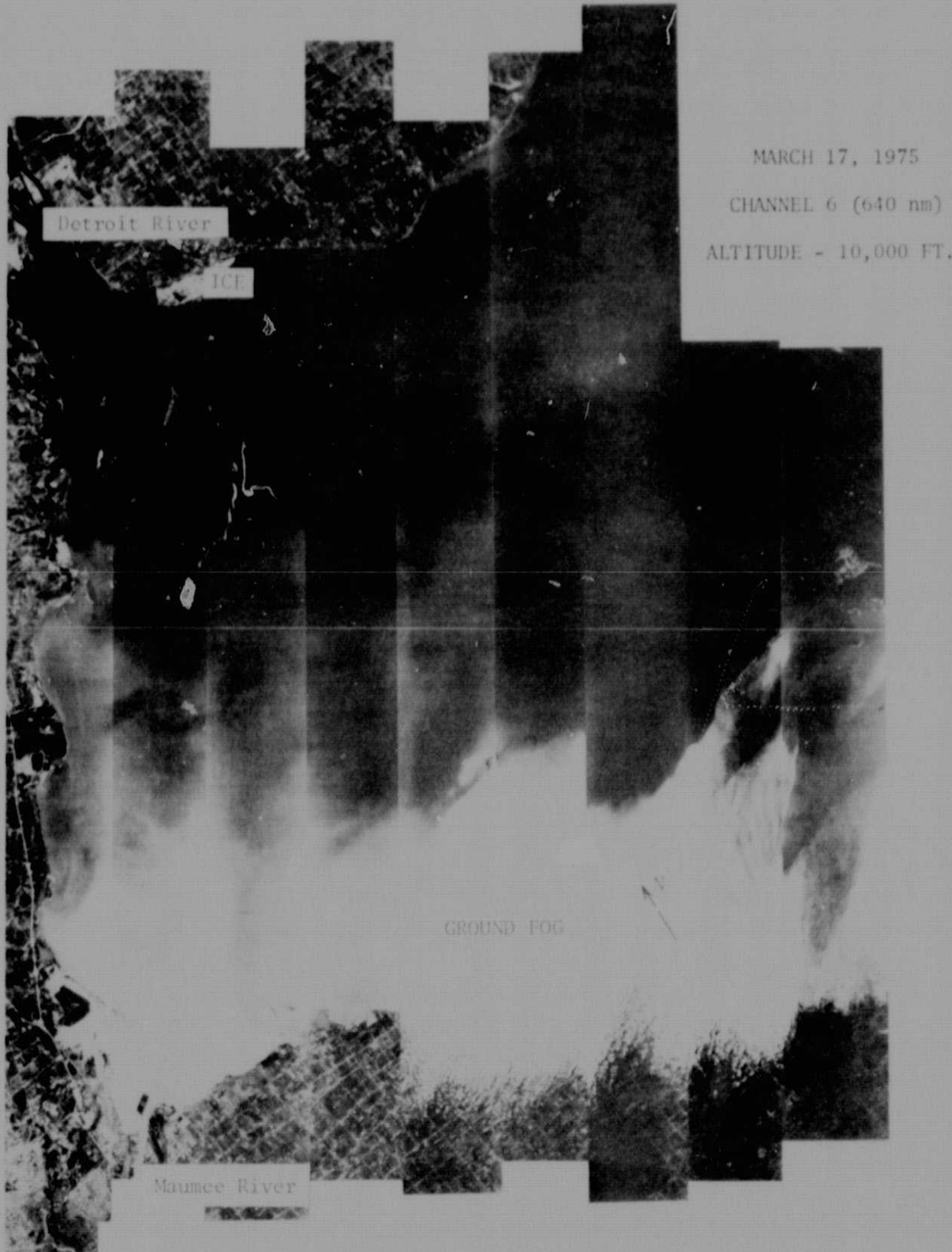

FIGURE 4

MULTISPECTRAL SCANNER IMAGERY OF WESTERN LAKE ERIE

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MARCH 18, 1975

CHANNEL 6 (640 nm) ALTITUDE - 10,000 FT.

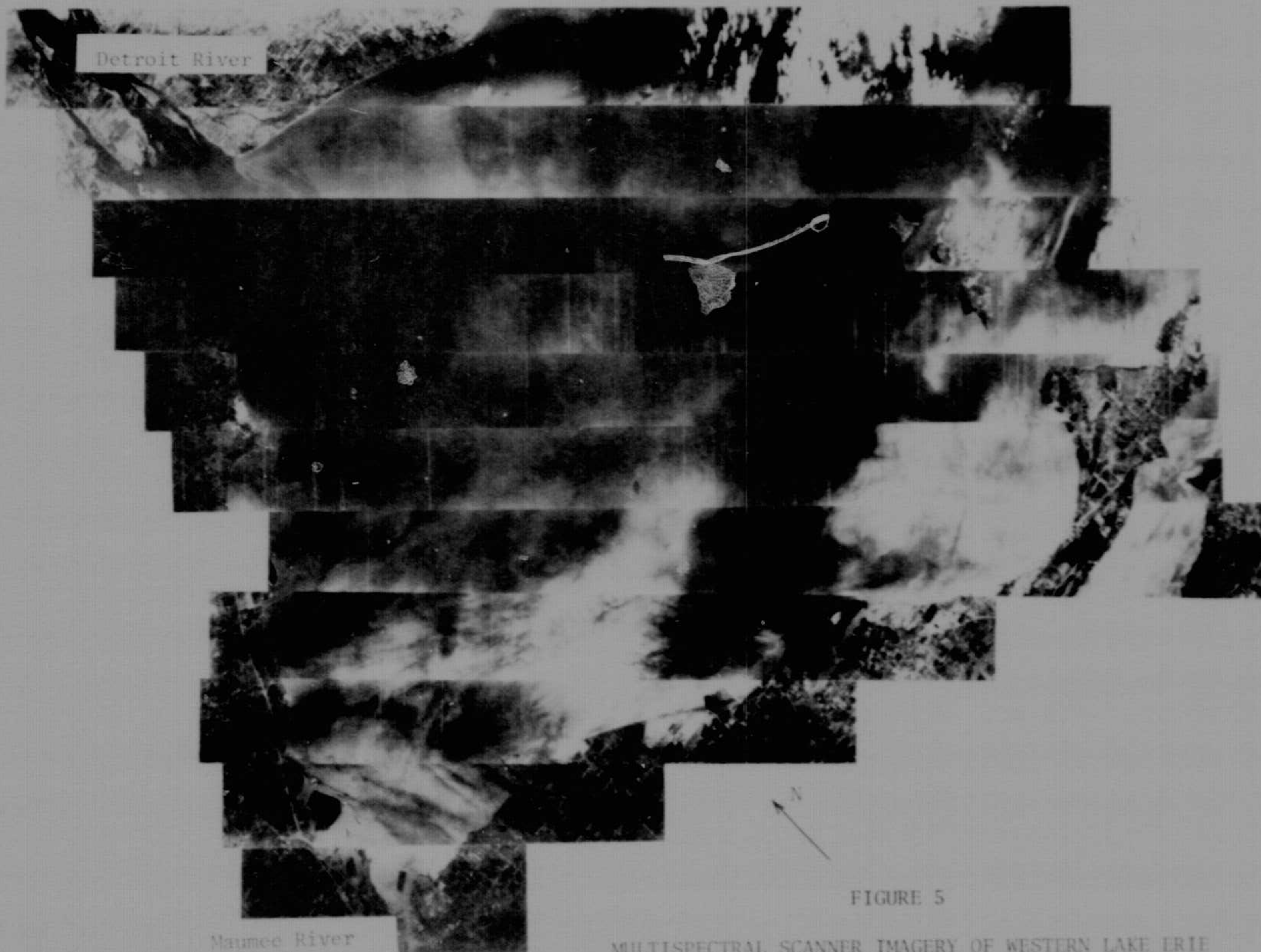


FIGURE 5

MULTISPECTRAL SCANNER IMAGERY OF WESTERN LAKE ERIE

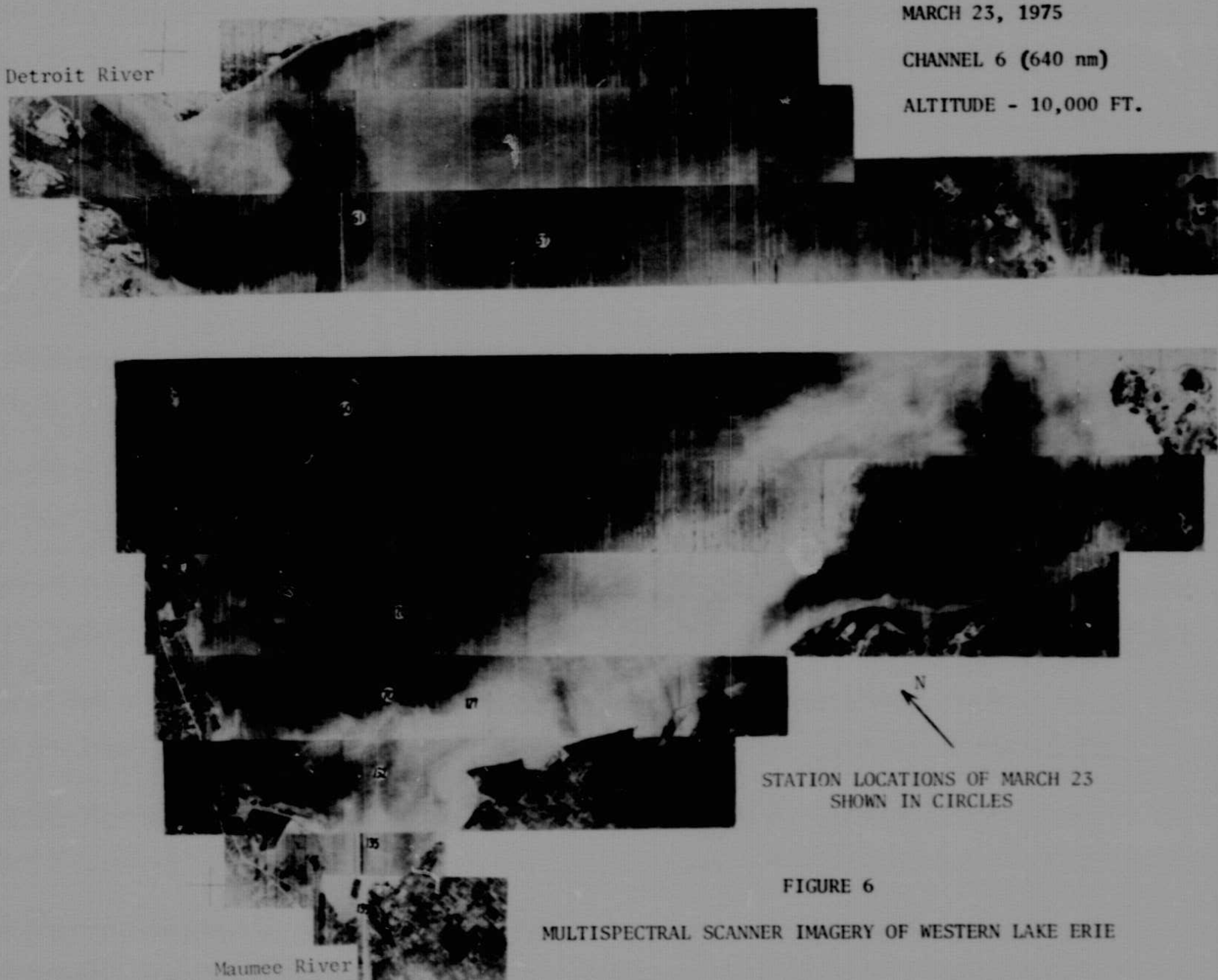
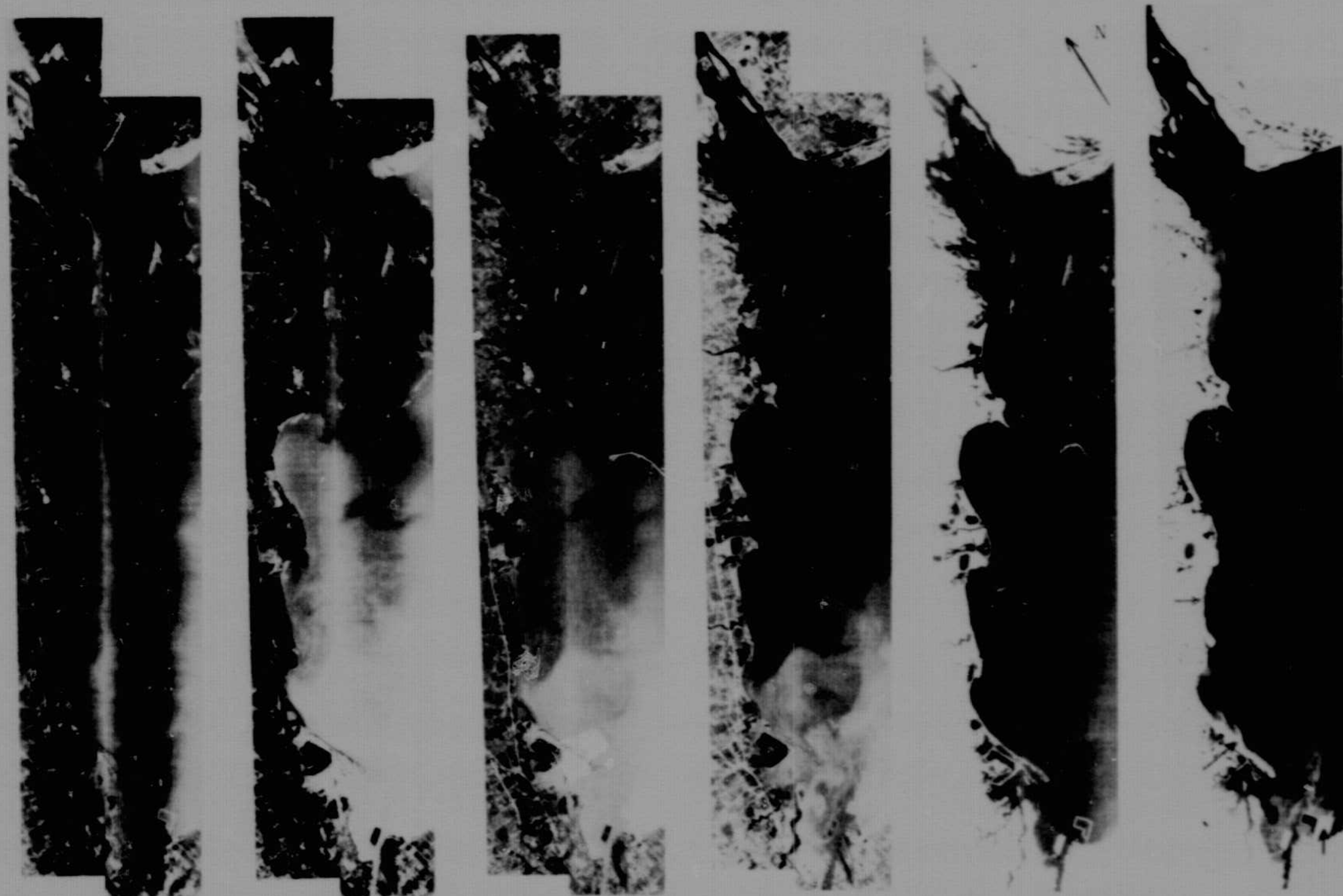


FIGURE 6

MULTISPECTRAL SCANNER IMAGERY OF WESTERN LAKE ERIE

MARCH 17, 1975 ALTITUDE - 10,000 FT.



CHANNEL 2 (465 nm) | CHANNEL 4 (560 nm) | CHANNEL 6 (640 nm) | CHANNEL 8 (720 nm) | CHANNEL 10 (1015 nm) | CHANNEL 11 (THERMAL INFRARED)

Arrows show power plant thermal plumes

FIGURE 7

MULTISPECTRAL SCANNER IMAGERY OF WESTERN LAKE ERIE

MARCH 23, 1975

CHANNEL 11 (THERMAL INFRARED) ALTITUDE - 10,000 FT.

FIGURE 8

MULTISPECTRAL SCANNER IMAGERY OF WESTERN LAKE ERIE

PARTICLE SIZE DISTRIBUTION

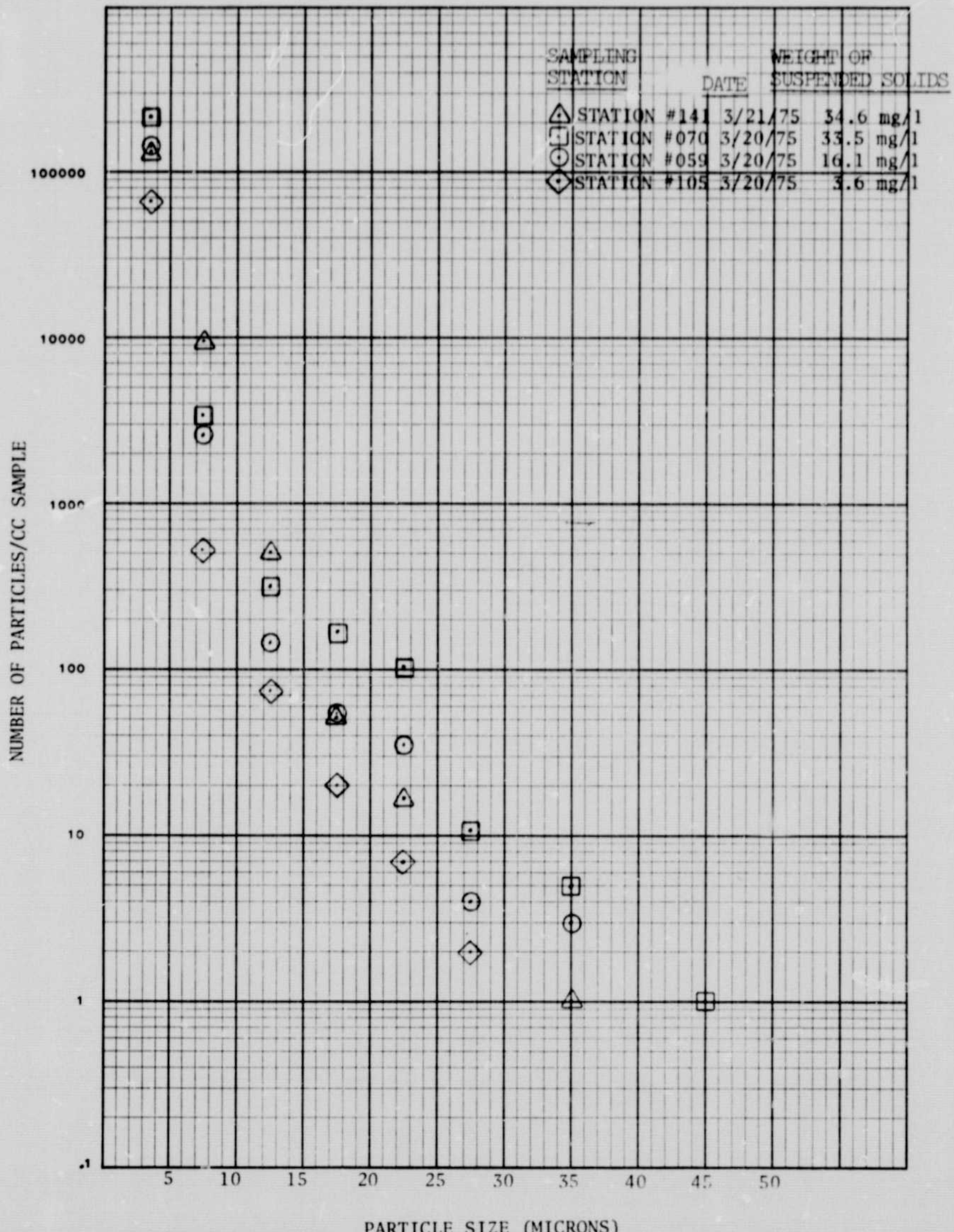


Figure 9